

## **TEMPERATURE AFFECTS GERMINATION INDICES OF SAFFLOWER (*CARTHAMUS TINCTORIUS* L.)**

O. Afzal<sup>1</sup>, F. U. Hassan<sup>\*1</sup>, M. Ahmed<sup>1</sup>, G. Shabbir<sup>2</sup> and S. Ahmed<sup>3</sup>,

<sup>1</sup>Department of Agronomy, PMAS-Arid Agriculture University, Rawalpindi, 46300, Pakistan

<sup>2</sup>Department of Plant Breeding and Genetics, PMAS Arid Agriculture University, Rawalpindi 46300, Pakistan

<sup>3</sup>Department of Agronomy, Bahauddin Zakariya University, Multan 60800, Pakistan

\*Corresponding author's email: [drsahi63@gmail.com](mailto:drsahi63@gmail.com)

### **ABSTRACT**

Seed germination based on temperature experience extensive deviation and considered as one of the earliest phenotypic expressions of the plants. Accurate assessment of the germination time under prevailing thermic regulations leads to optimized plant populations. Studying genotypic differences and microclimate during the early life are key indicators for specie recruitment. The research was carried out to quantify the impact of different temperatures on safflower genotypes. The seeds of five safflower genotypes (PI-16308, PI-16309, PI-16315, PI-26744 and PI-26748) were tested for germination at six constant temperatures (10, 15, 20, 25, 30 and 35 °C). Individual and coupled response of genotypes and temperatures revealed significant variation for germination percentage and germination index. Thermal regulation of germination percentage, germination index, mean germination rate, mean germination time, coefficient of velocity of germination, coefficient of variation of germination time, uncertainty of germination process and synchronization index were found highly sensitive to different temperatures. The maximum efficiency of above indices was recorded at temperature range of 15-20 °C. Based on these results it is concluded that temperature range between 15-20 °C is best suited for safflower planting to get the optimum plant population.

**Keywords:** Safflower, Germination rate, Germination percentage, Temperature Response

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### **INTRODUCTION**

Safflower (*Carthamus tinctorius* L.) is an annual crop belongs to *Asteraceae* family principally grown from arid to semi-arid regions (Asgarpanah and Kazemivash, 2013). It is usually cultivated for seeds which contains premium quality vegetative oil and used for dye extraction from flowers (Khalid *et al.*, 2017; Singh and Nimbkar, 2007). Being underutilized and neglected crop, small information related to its cultivation is available as compared to other major oilseed crops. Adaptability of unexplored crop to different agro-ecological zones needs to test the seedling establishment under varied temperature regimes. Among different agro-management practices time of planting is critical in view of crop weed competition and fertilizer management (Torabi *et al.*, 2015). Further, crop growth and development mainly influenced by the time of seedling emergence (Forcella *et al.*, 2000). Transition of seed from protected within seed coat to ambient environment, heterotroph to autotroph and quiescent to active growth stage are led by temperature and soil moisture conditions. (Donohue *et al.*, 2010).

Germination behavior of plants is strongly associated with existing habitat and local adaptation modulated by environmental such as temperature and

genetic factors (Ooi, 2012; Pendleton and Meyer, 2004). Environmental stimuli such as high temperature enhance perceiving germinability of *Acrocomia aculeata* L. especially during windows of climatic opportunities (Souza *et al.*, 2022). Germination capacity and rate are associated with base ( $T_b$ ), optimal ( $T_o$ ) and cardinal ( $T_c$ ) temperature (Alvarado and Bradford, 2002; Belmehdi *et al.*, 2018). Consequently germination characteristics are largely associated with the cardinal temperatures which determined the seed response to diverse environmental conditions (Khan *et al.*, 2022). Increasing annual average temperature continued from last few decades have significant impact on adapted species. Optimization of sowing temperature to get maximum germination rate under varied temperature ranges is necessary to determine time of sowing (Rotundo *et al.*, 2015). Cultivars or crops screening to understand their response under different temperature ranges help to identify best suited geographical areas where studied genotypes can potentially establish good crop stand (Derakhshan *et al.*, 2018). Seed germination is complex biological process in plant life cycle certain physiological changes takes place in seed under optimal germination conditions. Temperature is the major driving force affecting the germination and seedling establishment during adaptation of new species beyond the originated

regions (Kamkar *et al.*, 2012). Availability of appropriate temperatures conditions for uniform germination under rainfed conditions are very limited (Fakhfakh *et al.*, 2018). Prevailing temperature at germination time has momentous role to start physiological activity leading to seed rupture and establishment of plumule and radicle (Iannucci *et al.*, 2000). Studying different temperatures for germination indices helps to improve adaptation strategies to low and high temperatures environment for healthy crop stand (Al-Ahmadi and Kafi, 2007). Prediction of optimal planting date based on cardinal temperature potentially increase the crop yield due to appropriate plant population (Ramazani *et al.*, 2021). Increased temperature and low soil moisture at the time of sowing negatively affect subsequent seed germination whereas cold temperatures decrease physiological activities in the seed, hence results in poor germination (Iannucci *et al.*, 2000; Nagel *et al.*, 2015). Temperature is major modifying factor in the germination process affecting availability of soil moisture and nutrient supply for crop growth and development (Bocsi and Kovács, 1990). Prevailing temperature conditions directs the establishment of uniform seedling (Akinuoye and Modi, 2015). Optimum temperature range for germination and emergence of most of the crops ranged between 17 to 30 °C (Idikut, 2013). It has been established worldwide that seedling emergence is strongly negative correlated with low temperatures and drastically affect ultimate yield. (Birch *et al.*, 2003; Idikut, 2013).

Rate and percentage of germination are mainly dependent on the microclimate temperature (Bidgoly *et al.*, 2018). Moreover, germination %, mean germination time, and rate of germination under cold and warm temperature elaborates the fact that increased temperature positively improve germination (Soleymani, 2019). Seed germination has been analyzed by using a number of methods for data analysis. Each calculated parameter has different interpretation yet it is essential to study varied indices to check germination activity in given seed lot (Kader, 2005). Germination indices such as time, rate, and synchrony informed germinability dynamics and provides useful information to predict the unexplored specie success in different environments (Ranal and Santana, 2006). Safflower research particularly on its germinability under varying temperatures is limited. Identification of safflower genotypes that can germinate under different temperature regions will positively impact the safflower industry by opening a wide window to plant during early or late winters. Additionally, safflower genotypes collection from different geographical populations may exhibit differential response to changes in temperature. Therefore, determination of optimum temperature to get the desired plant population in the field is urgently required. Consequently, current study was carried out to 1) describe the safflower genotypic response to different temperatures and 2) optimizing the

best seedling establishment temperature to get the optimal crop stand.

## MATERIALS AND METHODS

Germination indices test of five safflower genotypes (PI-16308, PI-16309, PI-16315, PI-26744, PI-26748) was executed in Department of Agronomy, PMAS Arid Agriculture University, Rawalpindi in growth chamber (Model MLR-350H, SANYO Electric Co., Ltd. Japan). Experiments were started in September 2016 under different temperature regimes to check germination response. Germination count was made after 24 h of placement intervals until the completion or no further germination progression. Daily germination count was based on the radicle protrusion up to 2mm. Temperature of growth chamber were maintained at six temperatures (10, 15, 20, 25, 30 and 35 °C) and were kept constant during the experiment. Petri dishes were sterilized for 24 h at 120 °C to avoid any contamination. Three replicates of 10 seeds were maintained in petri dish of 10 cm on two layers of Whatman filter paper containing 10 ml of distilled water. Light duration was maintained at 12 hours a day. The following indices were calculated to quantify the genotypic response to varied temperature.

**Germination Percentage (%):** Germination capacity/percentage is one of the qualitative attributes usually converted into quantitative aspect based on dualistic response (germinated or non-germinated). It was estimated to check the seed viability of different genotypes. Germination capacity/percentage was calculated using following equation (ISTA, 2018).

$$\text{Germination percentage} = \frac{\text{Germinated seeds}}{\text{Total no. of seeds}} \times 100$$

**Germination index (Day):** Germination index describes best relationship between percentage and speed of germination. GI is estimated through following equation (Melville *et al.*, 1980).

$$G = \sum_{i=1}^k \frac{|(T_k - T) N_i|}{N_T}$$

Where,  $T_i$  Time between start of experiment and  $i$ th observation (day),  $N_i$  is germinated seeds in  $i$ th interval (It includes corresponding numbers to  $i$ th interval instead of accumulated count),  $N_T$  is Total number of seeds and  $k$  denotes total number of  $i$ th intervals.

**Mean Germination Rate (time<sup>-1</sup>) (MGR):** Mean germination rate is reciprocal of the mean germination time and was computed using following formula (Labouriau, 1983b; Labouriau and Viladares, 1976; Ranal and Santana, 2006).

$$V = \frac{\sum_{i=1}^k N_i}{\sum_{i=1}^k N_i T_i}$$

Where,  $T_i$  is time between start of the experiment and  $i$ th interval,  $N_i$  is germinated seeds in  $i$ th interval (It includes corresponding numbers to  $i$ th interval instead of accumulated count)

$k$  denotes total number of  $i$ th intervals.

$$V = 1/T$$

**Mean Germination Time (MGT):** Average time required for seeds to attain maximum germination is known as mean germination time. It is estimated according to following formula (Labouriau, 1983a; Ranal and Santana, 2006).

$$\bar{T} = \frac{\sum_{i=1}^k N_i T_i}{\sum_{i=1}^k N_i}$$

Where,  $T_i$  is time between start of the experiment and  $i$ th interval,  $N_i$  is germinated seeds in  $i$ th interval (It includes corresponding numbers to  $i$ th interval instead of accumulated count)

$k$  denotes total number of  $i$ th intervals. It can also be calculated by taking inverse calculation of mean germination rate.

$$\bar{T} = \frac{1}{V}$$

**Coefficient of velocity of germination (%) (CVG):** Measurement of germination rate has gained special attention of seed scientists among the germination indices. Germination rate was calculated by using the idea of (Kotowski, 1926) presented by (Nichols, 1968) as coefficient of velocity of germination.

$$C = \frac{\sum_{i=1}^k f_i}{\sum_{i=1}^k f_i x_i} \times 100$$

Where,  $f_i$  : Newly germinated seeds on  $i$ th day,  $k$ : Last germination day,  $x_i$  : Days taken to complete germination.

**Coefficient of variation of germination time (CV<sub>t</sub>):** It is estimated using following formula proposed by (Pimentel-Gomes, 1960; Ranal and Santana, 2006).

$$C = \frac{S_T^2}{\bar{T}}$$

Where,  $S_T^2$  is germination time variance,  $T$  is the mean germination time, However, The germination time variance was calculated by following expression,

$$S_T^2 = \frac{\sum_{i=1}^k n_i (T_i - \bar{T})^2}{\sum_{i=1}^k n_i - 1}$$

Where,  $\bar{T}$ : Mean germination time,  $T_i$ : Time between start of experiment and  $i$ th observation (day),  $n_i$ : Number of seeds germinated in  $i$ th time,  $k$ : Last germination time.

**Uncertainty of germination process (U) (bit):** Following expression was used to calculate uncertainty of

the germination process proposed by (Labouriau, 1983b; Shannon, 2001).

$$\bar{E} = \sum_{i=1}^k \int i \log 2 \int i$$

Where,  $\int i$  represents relative frequency of germination

$$\int i = \frac{N_i}{\sum_{i=1}^k N_i}$$

$N_i$  is germinated seeds in  $i$ th interval,  $k$  denotes total number of  $i$ th intervals.

**Synchronization Index (Z):** After germination, seed is known to be synchronized, and synchronization index ( $\bar{Z}$ ) is quantification of seed characteristic after its germination. Seed synchronized index was calculated by the expression presented by (Labouriau and Viladares, 1976).

$$Z = \frac{\sum_{i=1}^k C_{N_{i,z}}}{C_{\Sigma N_{i,z}}}$$

Where,  $C_{N_{i,z}}$  representing partially combination of the two germinated seeds from the whole population,  $N_i$  is germinated seeds in  $i$ th interval and were estimated by following expression.

$$C_{N_{i,z}} = \frac{N_i(N_i-1)}{2}$$

$C_{\Sigma N_{i,z}}$  representing partially combination of the two germinated seeds from the whole population at final count, presuming that all seeds that germinated did so instantaneously.

**Statistical Analysis:** Experimental treatments were replicated three times using CRD (complete randomized design) and each temperature was tested twice to reduce the experimental error. After generating the safflower germination indices for different genotypes under varied temperature regimes the pooled data were subjected to two-way ANOVA using Statistix 8.1 package. Treatment means were separated at  $p \leq 0.05$  for significant difference.

## RESULTS AND DISCUSSION

**Germination Percentage (%):** Germination percentage (GP) is one of the qualitative attributes usually converted into quantitative aspect based on dualistic response (germinated or non-germinated). Significant variation was recorded among genotypes and temperature ranges for GP ( $p \leq 0.05$ ) (Table 1). Overall germination percentage of genotypes ranged between 69.8 to 74.6 % depicted the viability of the germplasm (Table 2). These results indicate that temperatures changes did not affect genotypes germinability except the duration which was different

under each temperature. Highest (74.6 %) germination was observed for PI-26744 and the lowest (69.8 %) in PI-16309. Similarly, combined over genotypes germination % was between 67.8 to 77.6 % under different temperatures (Figure 1). Germination percentage at 30 and 35 °C were not statistically different. Correlation value ( $R^2 = 0.55$ ) between temperature and germination percentage suggests that higher temperature during the germination process is not suitable for optimum safflower crop density. Safflower capability to germinate under varied temperatures regimes suggests the potential of planting under diverse climatic conditions to increase the area under safflower cultivation. The significant interaction among safflower genotypes and temperatures (Table 1) is important to develop the accurate planting windows. Existence of interaction between genotypes and temperature are mainly due to some unique characteristics of the genotypes which perform better in specific conditions. Additionally, some genotypes are

more capable to perform under varied prevailing conditions. On the other hand, some genotypes needed more time to germinate. These characteristics of the safflower genotypes help to prioritize its planting over the other crops. Moreover, genotypic differences for germination capacity may be due to genetic response under prevailing temperatures. However, lower germination rate with increased temperature in winter crops is of great importance and provides basis for sowing time optimization. More than 70 % germination percentage occurred in the range of temperatures from 10-35 °C, thus depicted its potential to grow under varied ecological conditions. Varied temperature ranges regulate seeds dormancy status and subsequent establishment of seedlings were reported by Probert (2000). Similarly, (Campbell *et al.*, 2020; Xiao *et al.*, 2020) stated that optimal temperature ranges varies for specific crop species and drastic decline in germination at supra-optimal ( $> T_o$ ) or suboptimal ( $< T_o$ ) temperatures.

**Table 1.** Analysis of variance for interactive effect of genotypes and temperature on germination indices.

| Source         | DF | GP (%)    | GI (Day)  | MGR (Day)  | MGT (Day)  | CVG (%)    | CV <sub>t</sub> (%) | U (bit)    | Z          |
|----------------|----|-----------|-----------|------------|------------|------------|---------------------|------------|------------|
| Replications   | 2  | 22.07     | 31.3      | 0.00368    | 0.3545     | 36.45      | 22                  | 0.1932     | 0.01163    |
| Temperature(T) | 4  | 783.87*** | 3001.4*** | 0.58917*** | 83.1261*** | 5891.32*** | 4909.63***          | 17.1799*** | 2.25273*** |
| Genotype (G)   | 5  | 279.62*** | 55.3***   | 0.00171NS  | 0.1559NS   | 17.46 NS   | 26.67 NS            | 0.1165NS   | 0.01209NS  |
| T × G          | 20 | 477.58*   | 122.52**  | 0.00657NS  | 0.9998NS   | 65.47 NS   | 281.25 NS           | 0.4765NS   | 0.04606NS  |
| Error          | 58 | 779.27    | 157.94    | 0.023      | 2.4168     | 230.16     | 822.21              | 2.0105     | 0.17064    |
| Total          | 89 | 2342.4    | 3368.46   | 0.62413    | 87.0531    | 6240.87    | 6061.76             | 19.9766    | 2.49314    |

\*\*\* indicates probability level at 0.001, \*\* at 0.01 \* at 0.05, NS-Non-significant respectively

GP = Germination percentage, GI = Germination Index, MGR = Mean germination rate, MGT = Mean germination time, CVG = Coefficient of velocity of germination (%), CV<sub>t</sub> = Coefficient of variation of germination time (%), U = Uncertainty of germination process, Z = Synchronization index

**Germination Index (Day):** Germination index is the combination of variations in the germination and germination percentage among the genotypes. Significant variation among safflower genotypes was observed for germination index ( $p \leq 0.001$ ) (Table 1). Highest germination index (28.5) was observed for PI-26744 while PI-16309 showed lowest (26) (Table 2). Averaged over the temperatures genotypes PI-16308 and PI-16315 had similar germination index. These results elaborates that germination among the genotypes was not at the same rate due to distinct differences among them. Similarly, influence of temperature on GI was significant ( $p \leq 0.001$ ). Averaged over genotypes lesser value of germination index at lower temperatures and gradual increase was noted with increasing temperature and the highest was recorded at 35 °C ( $R^2 = 0.70$ )(Figure2). Total difference at lowest and highest temperature of 54 % confirms that per day germination of safflower genotypes was more rapid with increasing temperature. Interaction between genotypes and temperature regimes revealed significant difference at  $p \leq 0.001$  (Table 1). This interaction shows more differences among the genotypes

at lower temperatures compared to reduced differences at high temperatures. Highest index value was observed for PI-26744 at 35 °C while lowest was recorded for PI-16308 at 10°C. Germination index indicating the difference among temperature regimes for germinability (Kader, 2005; Singh *et al.*, 2021). Similarly, Javaid *et al.*, (2018) reported higher germination index values of *Salvia verbenaca* L under elevated temperatures indicates enhanced germination rate.

**Mean Germination Rate (MGR) (Day):** Mean germination rate (MGR) refers to the seed numbers germinated per unit time. Similar physiological quality of the grains does not respond differently for germination rate. Germination rate per day of studied safflower genotypes was non-significant ( $p \leq 0.05$ ) (Table 1). However, significant variation among different temperature for MGR elucidates the impact of increasing temperature. Averaged over genotypes highest germination rate per day (0.45) was noted at 35 °C and minimum (0.19) at 10°C (Figure 3). Calculated each day difference between maximum and minimum rate of

germination at different temperatures was 58 %. Rate of germinability was superior at 35 °C whereas slower physiological activity at 10 °C showed lowest value ( $R^2 = 0.91$ ). Gradual decrease in germination rate with decreasing temperature by 5 °C not only results in delayed emergence rate but also increase grains exposure to soil pathogens. These findings are in strong agreement with Torabi *et al.* (2013) who stated that germination rate of safflower severely affected by above and below optimal temperature ranges. Mean germination rate and temperature has linear positive relationship up to

optimum and negatively with above and below optimal ranges (Hardegree and Winstral, 2006). Similarly, faster germination rate of *Allium tenuissimum* L. was recorded at higher temperature within the range of  $T_o$  and  $T_c$  (Xiao *et al.*, 2020). Direct proportionality between germination rate and increasing temperature for *Chloris virgate* and *Digitaria sanguinalis* were noticed by Zhang *et al.* (2012). Conversely, Watt *et al.* (2010) were of the view that increased temperature beyond optimum level significantly reduced germination rate.

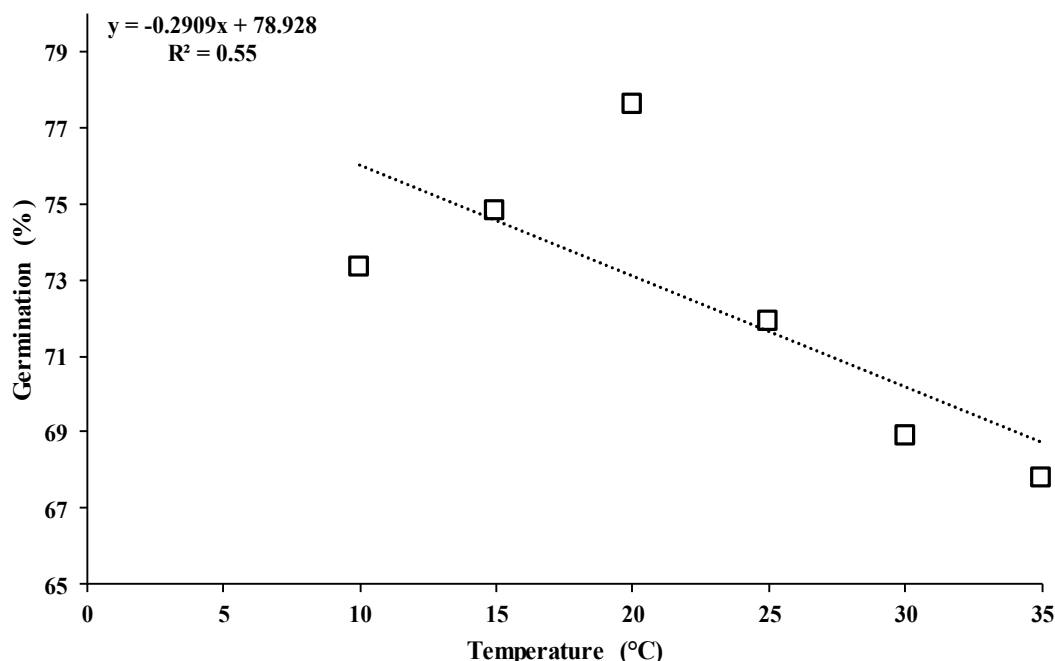
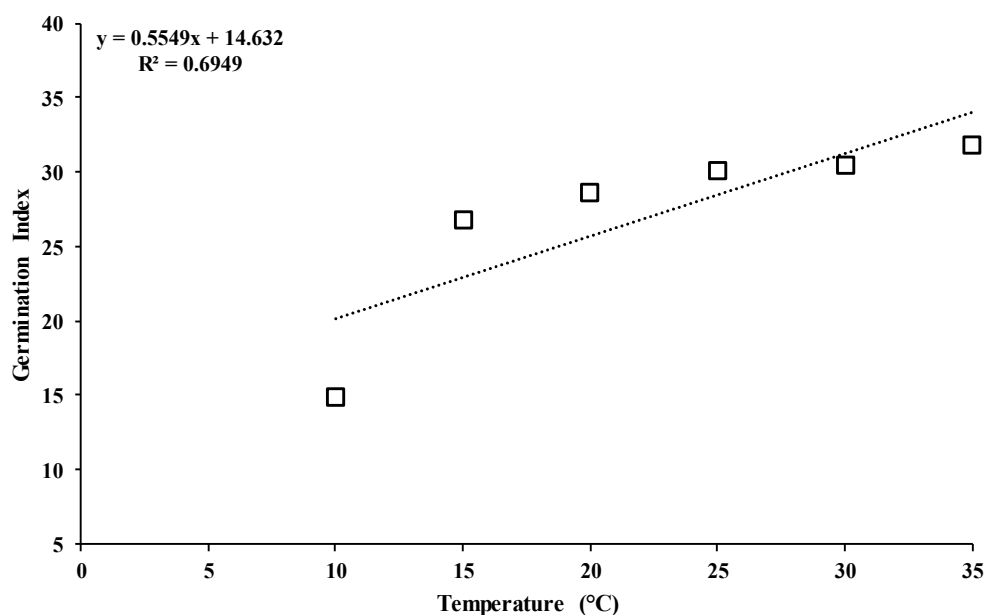


Figure 1. Effect of varied temperature regimes on germination (%) under different temperatures.



**Figure2. Effect of varied temperature regimes on germination index under different temperatures.****Table 2. Mean value of germination indices of varied genotypes.**

| Genotypes | GP (%)         | GI (Day)       |
|-----------|----------------|----------------|
| PI-16308  | 71.1 ± 0.71 bc | 26.9 ± 1.53 bc |
| PI-16309  | 69.8 ± 1.13 c  | 26.0 ± 1.5 c   |
| PI-16315  | 72.4 ± 1.08 bc | 27.1 ± 1.35 bc |
| PI-26744  | 74.6 ± 1.39 a  | 28.5 ± 1.52 a  |
| PI-26748  | 73.9 ± 1.36 a  | 27.3 ± 1.45 b  |
| LSD       | 2.36           | 1.10           |

Means in the same column followed by the same letters are not significantly different at 5% level of significance: NS= Nonsignificant GP = Germination percentage, GI = Germination Index, MGR = Mean germination rate, MGT = Mean germination time, CVG = Coefficient of velocity of germination (%), CV<sub>t</sub> = Coefficient of variation of germination time (%), U = Uncertainty of germination process, Z = Synchronization index

**Mean Germination Time (MGT) (Day):** Mean germination time is highly dependent on the temperature of microclimate. Gradual decrease in MGT with increasing temperature has often been noticed for different crops. Non-significant difference ( $p \leq 0.05$ ) among the genotypes for MGT showed the similar response of all genotypes under different temperatures (Table 1). Reduced germination time with increasing temperature could be due to enhanced physiological activity. However, considerable variation ( $p \leq 0.001$ ) for germination time under varied temperature regimes was noted (Table 1). The highest MGT (5.15 days) averaged over genotypes was recorded at 10 °C whereas, shortest duration (2.22 days) was recorded at 35 °C (Figure 4). Maximum MGT at 10 °C showed slower response of the seeds whereas, with increasing temperature lesser MGT values depicted good safflower genotypic acclimatization under different temperature ( $R^2 = 0.75$ ). These results demonstrate the genotypic response to high temperature and proved to be helpful information as longer the seeds would remained in the soil makes them susceptible to the predators or pathogens resulting the reduced plant stand uniformity (Queiroz *et al.*, 2019). The calculated difference for germination time at 10 and 35 °C was 57 %. Mean germination time results suggested that safflower has potential to germinate under wide range of temperature and such adaptation provides competitive advantage of cultivation under diverse climatic conditions. Similarly, Lobato *et al.* (2008) reported that increased temperature from 26-34 may provoked germination acceleration and reduce the mean germination time for sorghum. Moreover, gradual decrease in mean germination time with increasing temperature were observed for guar (Singh *et al.*, 2021; Tanveer *et al.*, 2020).

**Coefficient of Velocity of Germination (%):** Safflower genotypes were noticed non-significantly different for coefficient of velocity of germination ( $p \leq 0.001$ ) (Table 1). On the other hand, considerable variation among the temperature regimes showed highest velocity coefficient (45.2 %) was calculated at 35 °C and minimum (19.5 %) at 10 °C. Percentage difference between maximum and minimum velocity coefficient was 57 %. (Figure 5). Furthermore, interactive effects of safflower genotypes and temperature ranges were non-significant ( $p \leq 0.05$ ) (Table 1). High temperature (35 °C) provoked the enzymatic activity more rapidly than the lower temperature and speedup the germination process for all genotypes. Wide germinability thermal range and varied response to temperatures of safflower indicates its potential to successfully establish at diverse climatic conditions. Temperature is major driving force for germination process affecting speed of germination. Safflower seeds response to high temperature is sensitive and immediately start physiological processes of enzyme activation. Germination rate expressed by coefficient of velocity of germination precisely explain germination speed (Homrani-Bakali, 2015). In continuity with our findings, temperature based germinability test showed enhanced speed of germination at elevated temperatures while significant decrease at low temperatures were observed by Javanmard and Eshghizadeh (2014). In this study speedy germination process ( $R^2 = 0.91$ ) under higher temperature elucidates the capability of safflower to germinate even at high temperature. Supra-optimal temperatures ranges provides speedy germination in comparison with optimal and sub-optimal temperatures (Phartyal *et al.*, 2003).

**Coefficient of Variation of Germination Time (%) (CV<sub>t</sub>):** Per unit time variation in germination process under varied temperatures is important to study the varied impacts of low and high temperatures. Non-significant variation among safflower genotypes was recorded ( $p \leq 0.05$ ) (Table 1). However, considerable variation among different temperatures was observed. Highest germination time coefficient (39.7 %) was recorded at 15 °C followed by 20 (38.4 %) and 25 °C (38.3 %) whereas the lowest variation (21.5 %) was observed at 10 °C (Figure 6). Difference between highest and lowest variation coefficient of germination time was 46 %. Highest variation at 20 °C pertains optimum range of temperature for seed physiological response. However, extremes temperatures at both sides (lower & higher) such as 10 and 35 °C reflects lesser variation in germination process. Moreover, interactive effects of genotypes and temperatures were non-significant ( $p \leq 0.001$ ) (Table 1). Coefficient of variation of germination time variability measurement in relation to mean germination time provide additional comparison independently. Variation

among  $CV_t$  values are directly proportional to substrate temperature and increase with increasing temperatures from 21 to 32 °C ( $P = 0.01$ ) (Campbell *et al.*, 2020). Coefficient of variation of germination time precisely explains germination spread during the whole period and provides seed vigor information (Homrani-Bakali, 2015; Ranal and Santana, 2006). Moreover, variation coefficient at different temperature showed peak time between 15 to 20 °C and then gradual decrease with increasing temperature. These findings are in line with (Bradford and Nonogaki, 2008) who stated that germination is largely affected by lower and higher temperature resulting in U-shaped germination characteristics curve.

#### Uncertainty of Germination Process (U) (bit):

Uncertainty of the germination process is associated with the relative frequency distribution of the germination. Genotypes pooled over temperatures did not respond to uncertainty of the germination process differently ( $p \leq 0.05$ ) (Table 1). However, considerable variance among temperature regimes was noted averaged over genotypes. Highest uncertainty (2.01 bit) was recorded at 15 °C followed by 10 °C (1.92 bit). Lowest uncertain process of germination score (0.79 bit) was recorded at 35 °C (Figure 7). Percentage difference between highest and lowest uncertainty was 61 %. Uncertainty effects for interaction among safflower genotypes and temperature regimes were statistically non-significant ( $p \leq 0.05$ ). Gradual increasing temperature increase the uncertainty for all safflower genotypes and lowest value was obtained at 35 °C. These results are in accordance with Similarly, Ferreira (2018) who reported that gradual increase of constant temperature and uncertain germination showed inverse relationship for (*Mimosa bimucronata* L). However, Ávila *et al.* (2019) concluded uncertainty of the

germination process as inconstant process and lowest uncertainty was observed under 35 °C.

**Synchronization Index (Z):** Synchronization index was found non-significant for studied cultivars ( $p \leq 0.05$ ), whereas considerable difference was recorded for temperatures regimes ( $p \leq 0.001$ ) (Table 1). Highest synchronization index value (0.71) was calculated at 35 °C temperature while lowest synchrony (0.29) was observed at 15 °C followed by 10 °C (0.30) (Figure 8). Difference between highest and lowest synchronization index 60 % indicates huge difference due to temperature changes. Moreover, interaction among genotypes and temperature regimes were observed on-significant ( $p \leq 0.05$ ). Considering 20 °C as optimum temperature for safflower, less synchronized germination at below and above optimal temperature was recorded. These results indicate that high and low temperatures tend to be heterogeneous for germination of safflower. Increasing synchrony with increased temperature demonstrated positive correlation ( $R^2 = 0.83$ ) between temperature and synchronization index. Synchronization values closer to zero indicates more synchronized germination whereas generally higher values are considered as diversified index (Ranal and Santana, 2006). Similarly, Simão and Takaki (2008) were of the view that low values of synchronization index for *Tibouchina mutabilis* (Vell) under alternating and constant temperatures indicates wide germination distribution along the time. This germination index is regardless of the number of seeds that germinated its lower values represent more synchronized germination (Lopes *et al.*, 2015). Increased synchronized seed germination score also indicates physiological homogeneity of the seed lot at germination time (Conserva, 2007).

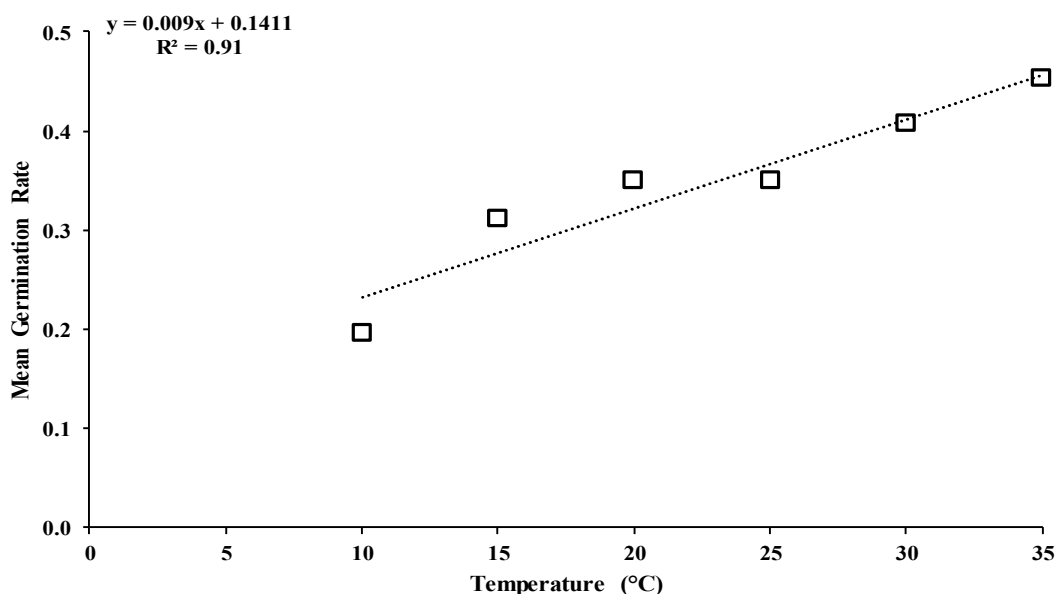


Figure3. Effect of varied temperature regimes on mean germination rate under different temperatures.

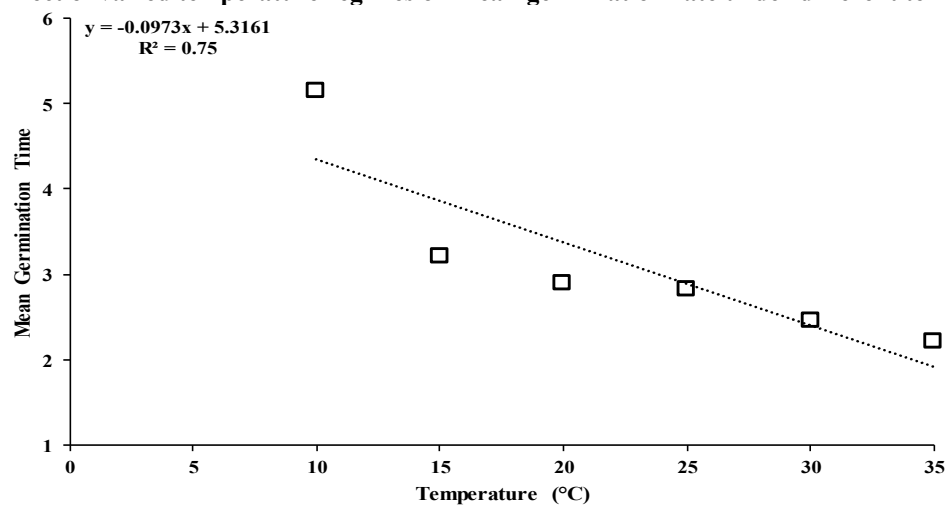


Figure4. Effect of varied temperature regimes on mean germination time under different temperatures.

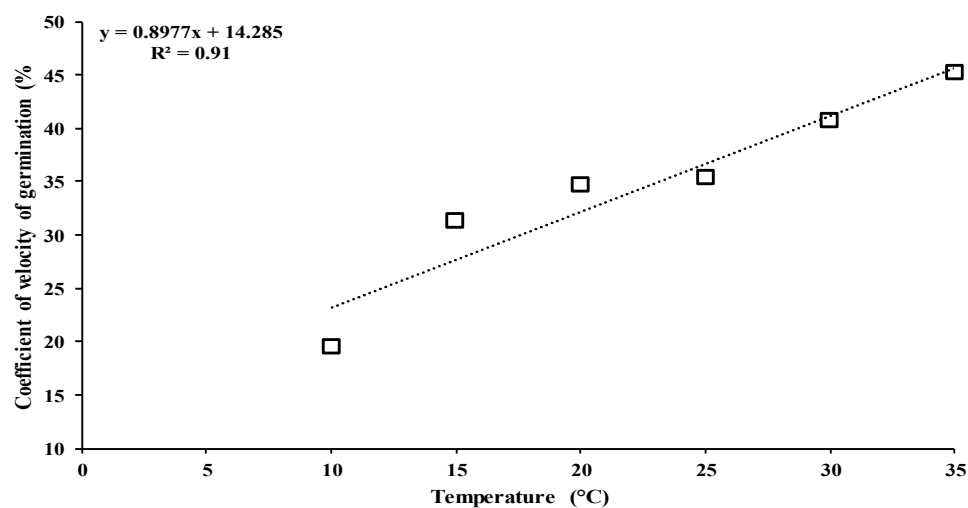
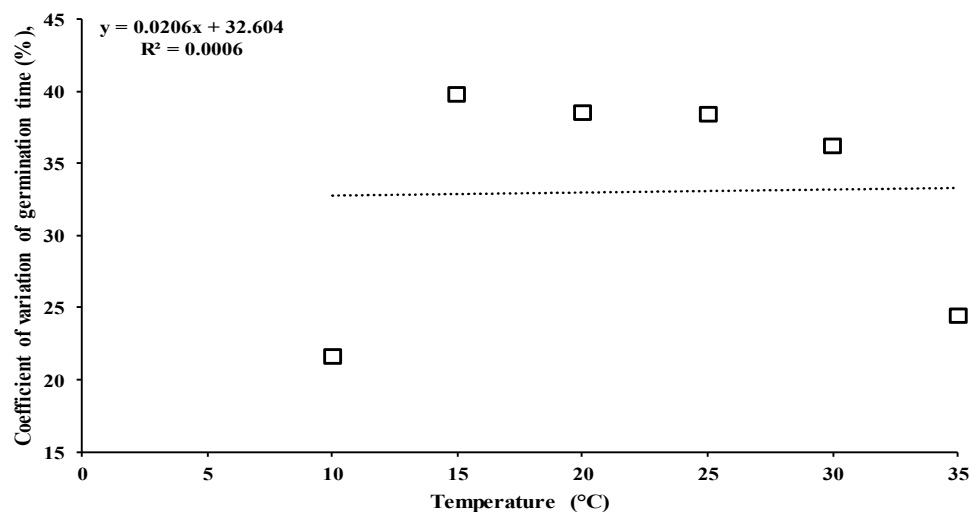
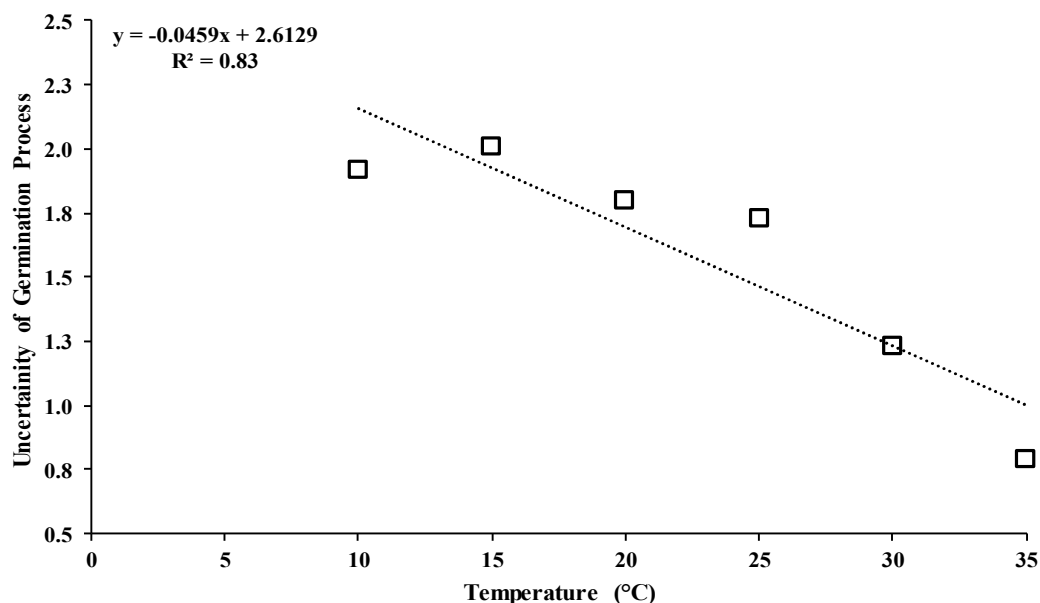


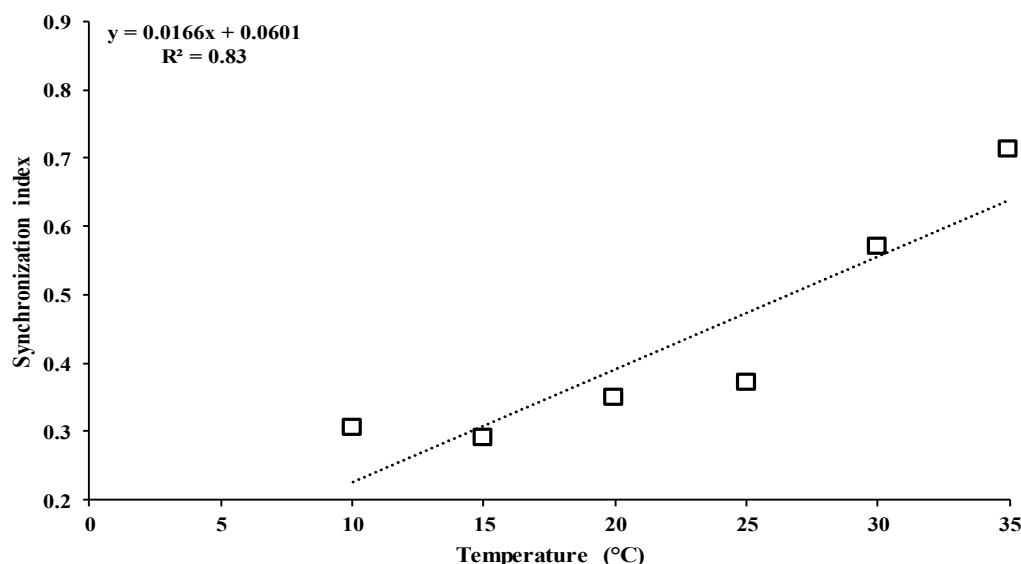
Figure5. Effect of varied temperature regimes on coefficient of velocity of germination under different temperatures.



**Figure6.** Effect of varied temperature regimes on coefficient of variation of germination time under different temperatures



**Figure7.** Effect of varied temperature regimes on uncertainty of germination process under different temperatures



**Figure8.** Effect of varied temperature regimes on Synchronization index under different temperatures

**Conclusions:** Results of different indices elaborates that optimum germination count ranges between 15-20°C which is comparable to optimum temperature for growing safflower under varied areas. Therefore, gradual increasing temperature provoked germination acceleration and reduce the mean germination time for uniform seedling establishment. Identification of genotype capable of germinating under the range of temperatures may provide opportunities to cultivate under diverse agro-ecological zones. Hence, studied genotypes

proved to be adaptable to germinate under varied temperature regions under rainfed conditions.

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